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CONSTRUCTION OF RETARDING POTENTIAL ANALYZER CALIBRATIONS FILES FOR THE CHAWS EXPERIMENT

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This report summarizes the construction of calibrations files for the CHAWS retarding potential analyzer (RPA) detectors. Calibrations data taken in the MUMBO vacuum chamber using the CALSYS system are analyzed. The six CHAWS RPA apertures, three on ram side and three on the wake side, were represented by means of data lines which emanate from the center of each detector. Methods and routines were developed to build the calibrations files which depict the average aperture response as a function of the polar and azimuth angles with respect to the aperture normal.

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1. INTRODUCTION

This report describes the construction of calibrations files for the retarding potential analyzers (RPA) for the CHAWS [*Cooke, et al.*, 1994; *Enloe, et al.*, 1993; *Tautz*, 1992] experiment. These files were used as inputs to further programs which calculate the detector efficiencies as a function of Mach number. The detector efficiency files have subsequently been used as inputs to the CHAPS and CHUNKS codes [*Roth*, 1996] to enable particle fluxes and densities to be calculated.

The CHAWS experiment has sixteen RPA sensors. There are eight sensors on the ram side of the shielding disk and another eight on the wake side. The locations and orientations of these detectors are shown schematically in Figure 1. In the figure, the arrows depict the outward normals for the apertures. The diagram is not to scale. The ram side detector normals are at angles of +40 and -40 degrees from the center normal.

Calibrations data for both ram and wake sides was taken using the CALSYS/2 system and the MUMBO vacuum chamber [*Pakula and Cooke*, 1995]. This data consisted of counts/sec in each of the sixteen detectors for varying beam currents and different orientations with respect to the beam. The data was processed in terms of the summed response of each of the detector apertures. Thus, there were six cases to be treated:

ram outboard	-	channels 1,2
ram center	-	channels 3-6
ram inboard	-	channels 7,8
wake end	-	channels 9-12
wake outboard	-	channels 13,14
wake inboard	-	channels 15,16

The calibration data for the RPA sensors was initially analyzed by fitting the measurements to analytic functions (trigonometric expansions and some variants of these were tried), but this procedure was found not to give reliable and intuitive results in all cases, due to the variability of the measurement data. Therefore, we have used instead a more direct method, that of reducing the data to manageable form by implementing an averaging procedure. The ram side averaging is based on a method which generates interpolated calibration data along lines emanating outwards from the center of each aperture. This lines data can then be averaged down to represent the response of each detector, as a function of the polar and azimuth angles with respect to the aperture normal. The resulting calibrations files thus consist of a matrix of numbers, with the rows representing the response along the aperture polar angle and the columns giving the response with respect to the azimuth angle. Files of the same format were constructed for the wake side detectors, although the method of averaging varied according to each detector, due to the sparsity of the data.

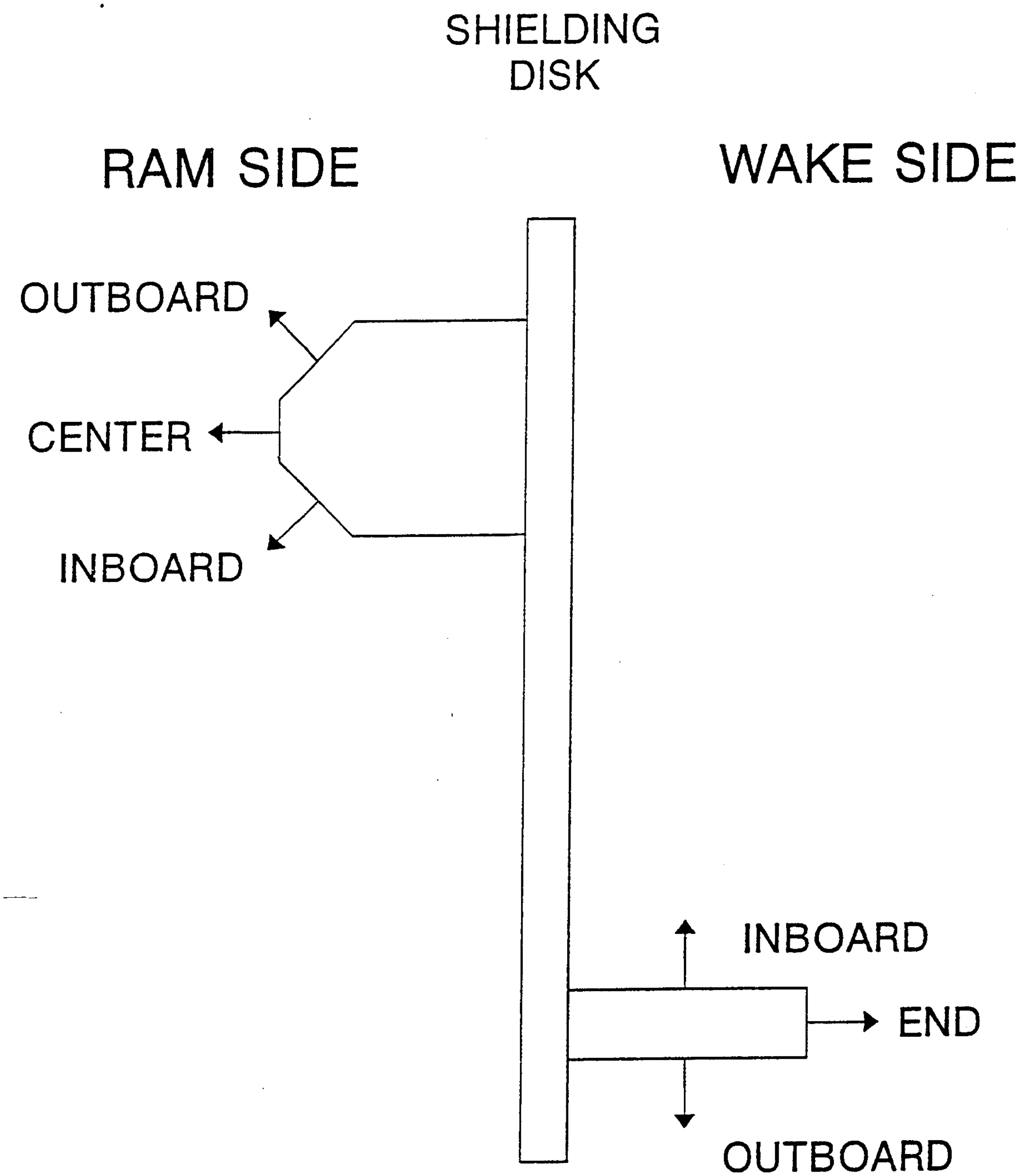

Figure 1. Schematic of CHAWS RPA detectors.

The analysis was done on a Silicon Graphics workstation under the UNIX operating system. To supplement this report, documentation has been included "on-line" in the form of README files. Figure 2 shows the directory structure for the analysis. At the top of the tree, there is a README_calibrations file with a description of where things are located. The top directory also contains the IDL procedures which were written to produce graphical output for the analysis. Most of the subdirectories contain a README file with local information. The subdirectory "report" contains text files and figures for this report. The subdirectories "ram_cals" and "wake_cals" head the data files and calculations done for the ram and wake side analysis, respectively. It is intended that this directory be maintained and archived to serve as a further reference to this work. Section 2 of this report summarizes the ram side analysis, Section 3 outlines the wake side averaging procedures, and Section 4 summarizes the results.

2. RAM RPA SENSOR DATA

The ram side sensor calibrations data was taken with the CALSYS system in the MUMBO vacuum chamber. The detectors were mounted facing the beam and CALSYS motors were used to scan vertically and horizontally. The scans proceeded through the horizontal range, then jumped vertically and reversed the horizontal motion. The detector response in the 8 ram RPA channels was measured simultaneously at each CALSYS angle. At the beginning and end of a scan, the beam current was recorded. The scans were interlaced, i.e., in order to minimize the problem of calibration beam variance over the course of the scan, sets of two (or three) scans were done with identical angle step sizes, but with the starting angles offset from each other. The typical angular step size was 4 degrees, and the offset 2 degrees. The angle convention for the CALSYS horizontal motion was that a positive angle moves the detector normal to the right, looking into the beam. A positive vertical CALSYS angle moved the detector normal down, towards the floor. The CALSYS data for the scans was put into a set of ASCII files for analysis [*Pakula and Cooke*, 1995].

The analysis of the ram side sensor data was done using the following steps:

1) the "raw" CALSYS data files were converted to "normalized" data files.
2) lines in the detector frame (polar angle varying at fixed azimuth) were generated, and a transformation to the corresponding CALSYS angles was done. From the CALSYS angles, the values at the points were calculated using bi-linear interpolation in the CALSYS normalized data grid.
3) the lines of interpolated data was condensed by averaging down the polar angle points by a 5:1 ratio. Background levels were estimated.
4) any regions with missing data points were filled in using an average profile obtained from the neighboring complete data samples.

The tree for this analysis was shown in Figure 2 under the ram_cals directory. Each of the steps will be described in more detail below.

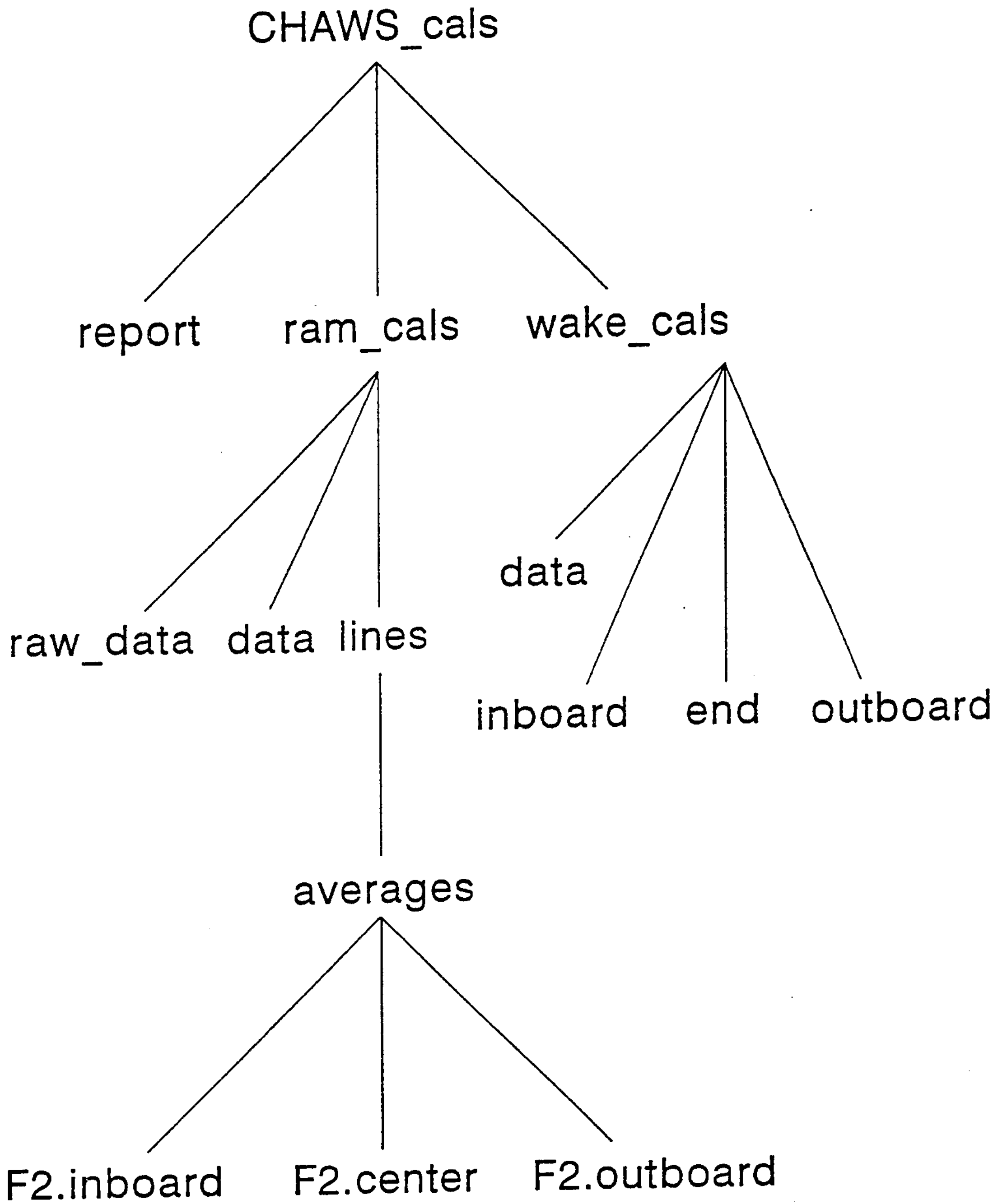

Figure 2. Schematic of Analysis Directory Tree.

2.1 STEP ONE: CREATE NORMALIZED DATA FILES

The ram side sensor "raw" calibration data taken with the CALSYS system in the MUMBO chamber consists of a set of ASCII files in the following format. At the top and bottom of the file there is a measurement value for beam current (pAmp). The middle of the file consists of the measured counts for each of the eight RPA channels. The format of each row is two floats followed by 8 integers. The floating point numbers represent the CALSYS horizontal and vertical scan angles and the integers represent the channel counts. A script, "do_awk", was written to read these files and produce a file of "normalized" data. The normalized data files have the following row format:

angle1 angle2 current f1 f2 f3 f4 f5 f6 f7 f8

where angle1 = CALSYS y (vertical) scan angle, unchanged from the raw data file
angle2 = CALSYS x (horizontal) scan angle, unchanged from the raw data file
current = linearly interpolated current, obtained by scaling the measured values from the top and bottom of the raw file
f1 to f8 = counts/current for each of the eight ram channels

This work was done in the subdirectory ram_cals/data.

2.2 STEP TWO: GENERATE DETECTOR LINES DATA

A FORTRAN program, "lines.f", was written to read the normalized data files and write the lines files. The method used was as follows:

1) The data is read in and sorted into a regular grid, i.e., the horizontal scan angles are reordered so that they increase monotonically.
2) The program loops on polar(fastest) and azimuth angle in the detector frame.
3) The detector coordinates are transformed into CALSYS frame coordinates.
4) The value at the CALSYS point is obtained using bilinear interpolation in the CALSYS grid box containing the point. Note that this procedure works with both the interlaced and non-interlaced scans.
5) The lines are output to a file with the row format:
azimuth polar current f1 f2 f3 f4 f5 f6 f7 f8

where azimuth = azimuth angle in detector frame
polar = polar angle in detector frame
current = interpolated current
f1 to f8 = interpolated counts/current

Notes:

- we have used azimuth angle spacing of 7.5 degrees and polar angle spacing of 1 degree to roughly match the CALSYS angular resolution.
- the normalizing interpolated current is carried along for convenience; it is not actually used in subsequent steps.
- the interpolated data values typically lie between 0.0 and 0.6.
- the transformation to CALSYS (x, y) angles from detector angles (p, t) is given by: $\sin(y) = \sin(t)*\cos(p)$ $\tan(x) = \tan(t)*\sin(p)$
- Figure 3 shows the mapping of the detector lines into the CALSYS grid. The detector azimuth increases by 7.5 degrees in the clockwise direction and the detector polar angles increases by 1 degree steps along the lines. The choice of a clockwise direction is arbitrary and was switched to counter-clockwise to conform with subsequent programs.
- if the CALSYS point (x, y) is outside the CALSYS grid, a hard zero was returned.
- the side detector data was handled by shifting the CALSYS horizontal angle by -40 degrees for channels 1,2 and +40 degrees for channels 7,8.

This work was done in subdirectory ram_cals/lines.

2.3 STEP THREE: AVERAGE DOWN THE DATA LINES

A FORTRAN routine, "averages.f", was written to make averages of the lines file data. This routine takes three command line arguments:

1) The flight number which specifies the case to be considered. This option currently supports just the present case.
2) The ram detector aperture. There are three choices: center, inboard, and outboard.
3) The estimated background. This is set to zero initially, then can be upgraded iteratively.

The actions performed by the averaging program are summarized below. The code loops over the lines data files for the different measurement cases:

- for each input data file, it loops over azimuth angles.
- for each azimuth angle, it reads in all the polar angle data.
- it sums over the channels corresponding to the selected ram detector aperture.
- it reduces the polar angle data from 1 degree bins to 5 degree bins.
- it stores this information in memory.

A second loop is then done over azimuths and reduced polar angles to calculate the averages over the input data files. Only cases with non-zero data are included in this averaging. The estimated background may be subtracted at this point.

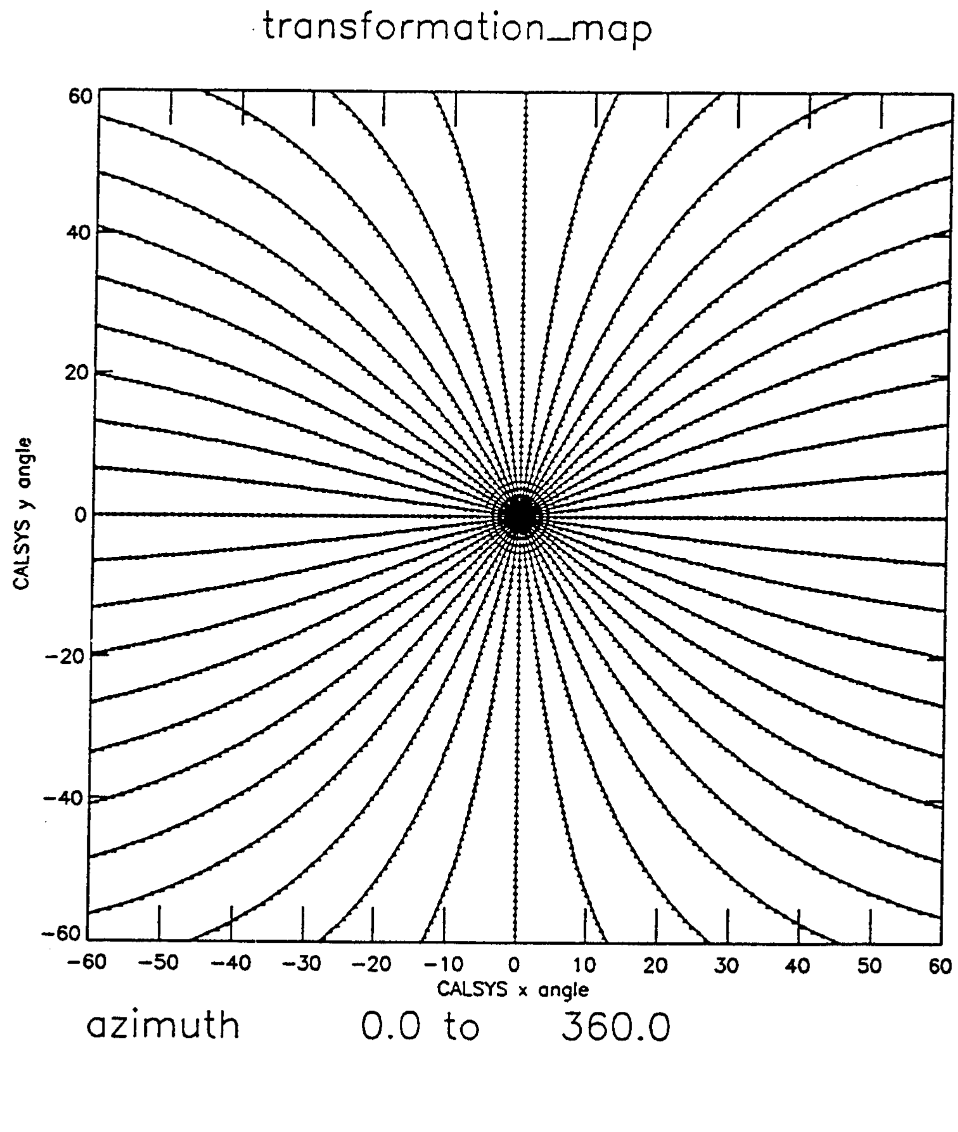

Figure 3. Detector to CALSYS transformation.

Notes:

- The polar angle reduction is done by a five point central average i.e. the average of the current polar angle and the two neighboring points above and below this point. The end points of the line get special treatment.
- For the first point, the average is taken over the first three data values.
- For the last point, averages are done as follows:
  - if the last point falls at the end of data, take a three point average using the three points below the point.
  - if the last point falls one short of end of data, take a four point average using the two points below and one above it.

As this study was done to set pre-flight calibrations, the cases to be used were those measurements that were made after all final changes had been made to the detectors. All available ram center and inboard data was good (8 files), but the outboard detector data was only good after a micro channel plate (MCP) replacement (3 files). The beam energy in all cases was 20 ev.

Runs were made with and without background subtraction. The subtraction was done by making two (or more) passes with the averaging code. On the first pass, the output table was looked at and a visual estimate of the background was made. This estimate was given to the averaging code as a command line argument and the program was rerun. The background subtraction was performed and a new table was produced for re-inspection. The background determines the sensitivity to the high polar angle data. A decision as to the amount of background subtraction can be made based on comparison of density calculated for the ram center and side detectors.

The work was done in subdirectory averages_b or averages_nb, depending on the background calculation.

2.4 STEP FOUR: FILL IN ANY MISSING LINES DATA

The mapping from the detector angles to CALSYS angles can result in points outside the range of the measured CALSYS grid. To fill in these missing points, we have made use of existing complete data in neighboring regions. A series of awk scripts were written to calculate an average profile for any complete data in the region. The detector angle space was typically divided into four quadrants and a profile was computed for each quadrant. A FORTRAN program, "profile.f", was written to join these profiles to the end of the incomplete lines, and thus extend them out to the full detector range. The join was made by matching the last point of the data line to the first point used in the profile by scaling. Subsequent profile values were linearly scaled down, such that the last value was multiplied by one.

The final result is an matrix of data values averaged over the various input files. The rows of the matrix specify the detector azimuth angle and the columns represent the reduced polar angle. This

information is written to an output ASCII file in the form of a table.

This work was done in directories below those for calculating the averages.

2.5 IDL PLOTS

An IDL procedure, 'idl_conts.pro', was written to display the normalized ram data on the CALSYS grid. This program reads in the data and displays it on a two dimensional contour plot.

Figures 4 and 5 show the ram calibration data for the center detector for all of the data that was used. The data represents the sum of counts/current for the channels 3, 4, 5, 6. Contour levels of 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6 are shown. The horizontal axis represents the CALSYS x angle, and the vertical axis represents the CALSYS y angle. The cases are labeled by the day of measurement and a number which indicates the interlacing status (even number cases are offset from the odd number cases). It can be seen that the data is incomplete, in that the CALSYS measurements did not extend fully in the vertical direction.

A second IDL procedure, 'idl_lines.pro', was written to read the lines files and display the one dimensional profiles through the data.

The top of Figure 6 shows the lines calculated for the center detector. Each line represents a different azimuth angle, spanning 7.5 to 360 degrees in 7.5 degree steps. In order to check that these lines give a reasonable depiction of the input CALSYS data, the following test was made. A program was written to reconstruct a CALSYS data file corresponding to the final calibrations file. This was done by setting up a loop over the CALSYS x and y angles and calculating the corresponding detector angles (using the inverse transformation). At each point, the interpolated data value was calculated from the calibration data, and this information was written out into a file in the same format as for the measured data files. This file was then read and displayed, using the same IDL procedure, 'idl_plots', as for the input data. The result is shown at the bottom of Figure 6. One can see that the general shape of the measured contours is well represented, and that the missing data regions have been filled in.

Figure 7 shows the normalized and the reconstructed data for the ram outboard detector. The shape of the reconstructed contours is similar to the center detector data, and the missing data has again been filled in.

Figure 8 shows the normalized and the reconstructed data for the ram inboard detector. In the reconstructed data, the missing data has again been filled in. However, the shape of the distribution is anomalous, indicating that there was a problem with the RPA sensor.

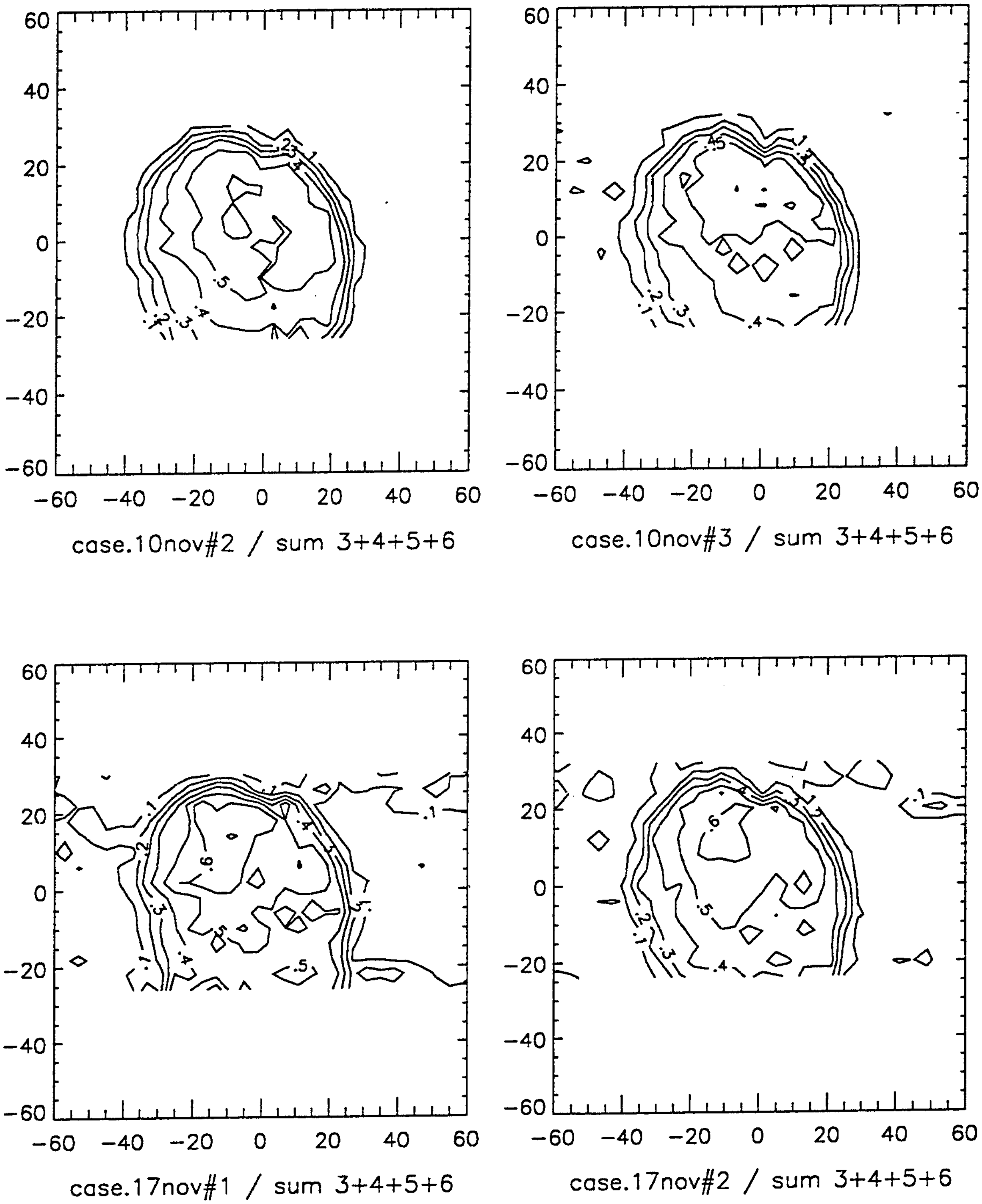

Figure 4. Ram center detector CALSYS data for nov 10,17.

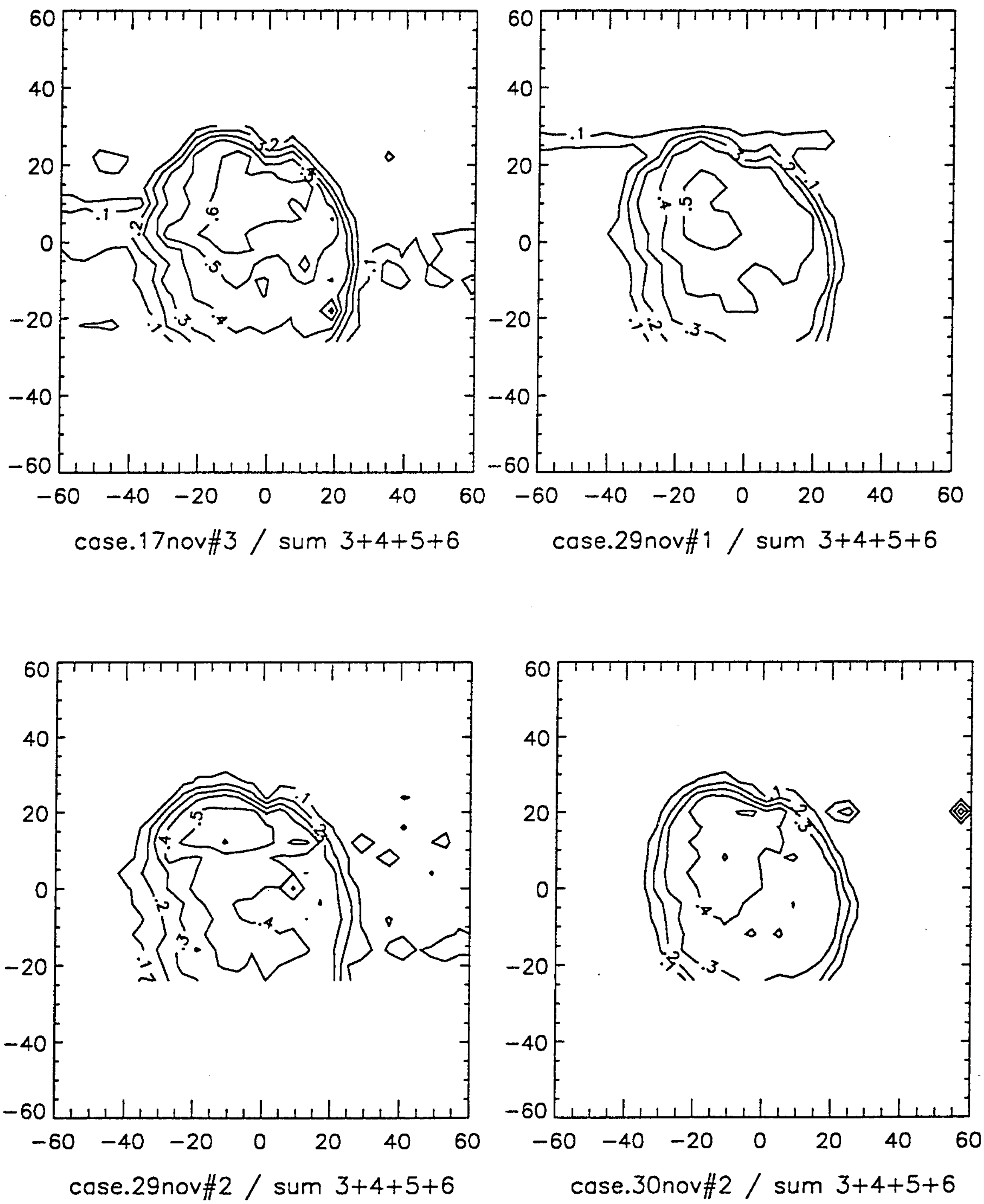

Figure 5. Ram center detector CALSYS data for nov 17,29,30.

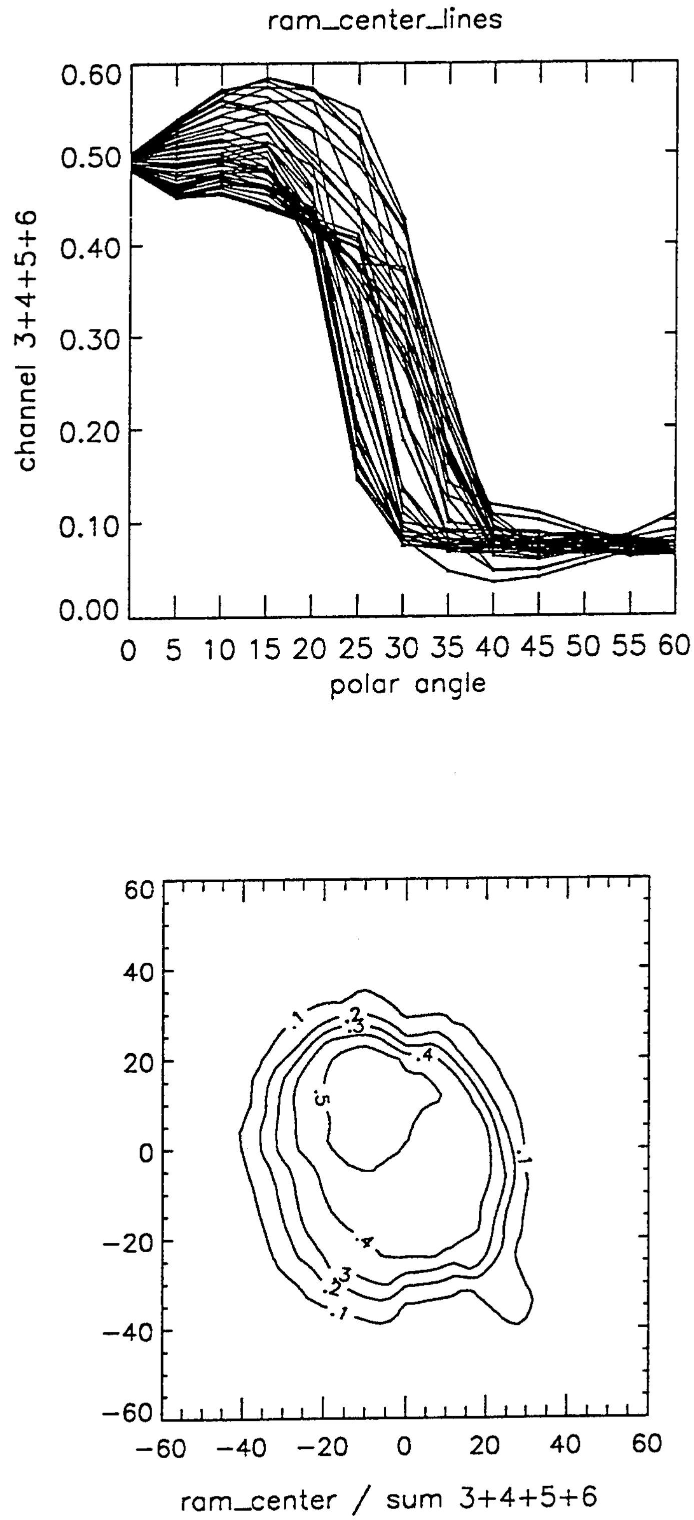

Figure 6. Ram center detector data lines and reconstructed CALSYS data.

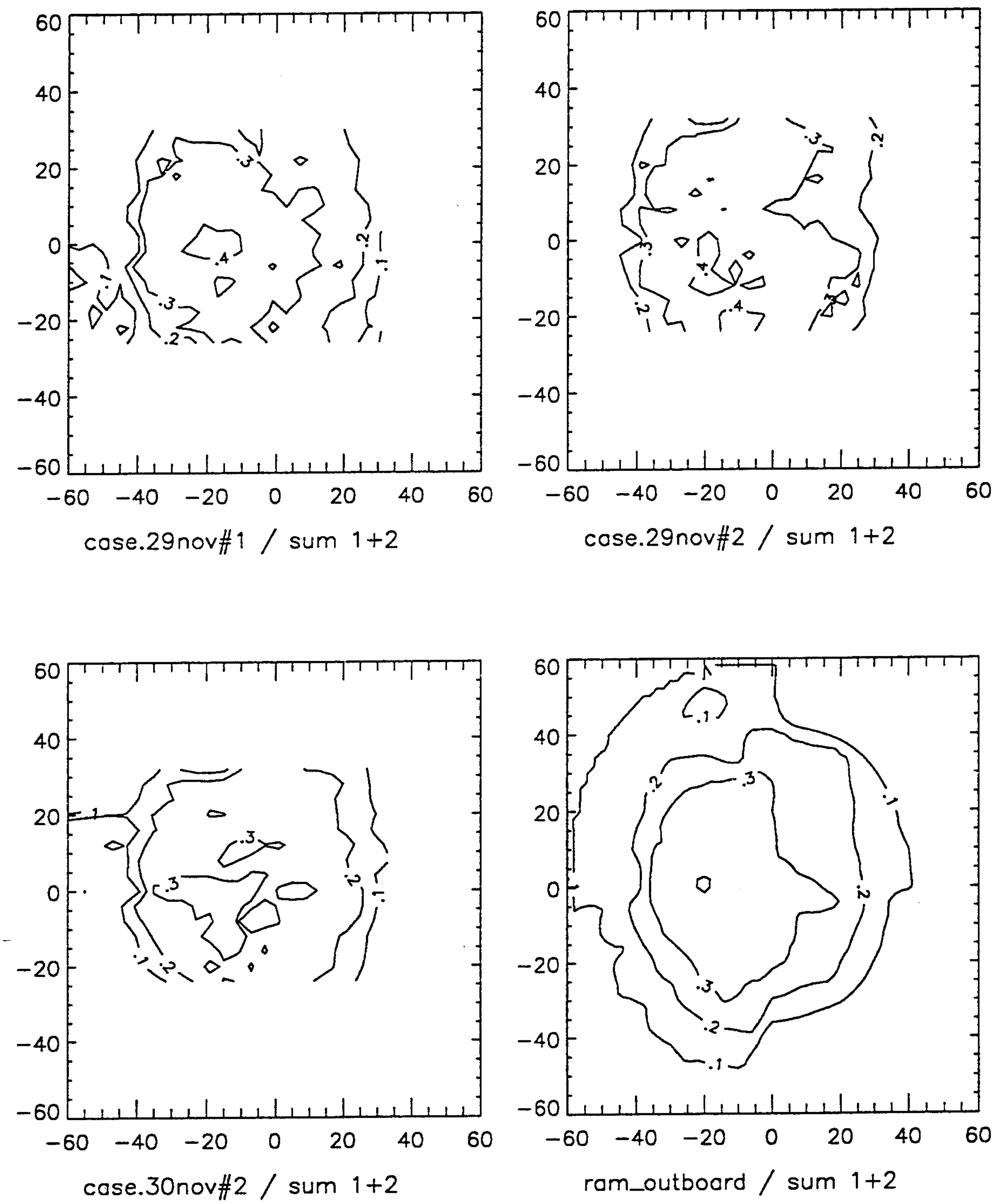

Figure 7. Ram outboard detector data and reconstructed CALSYS data.

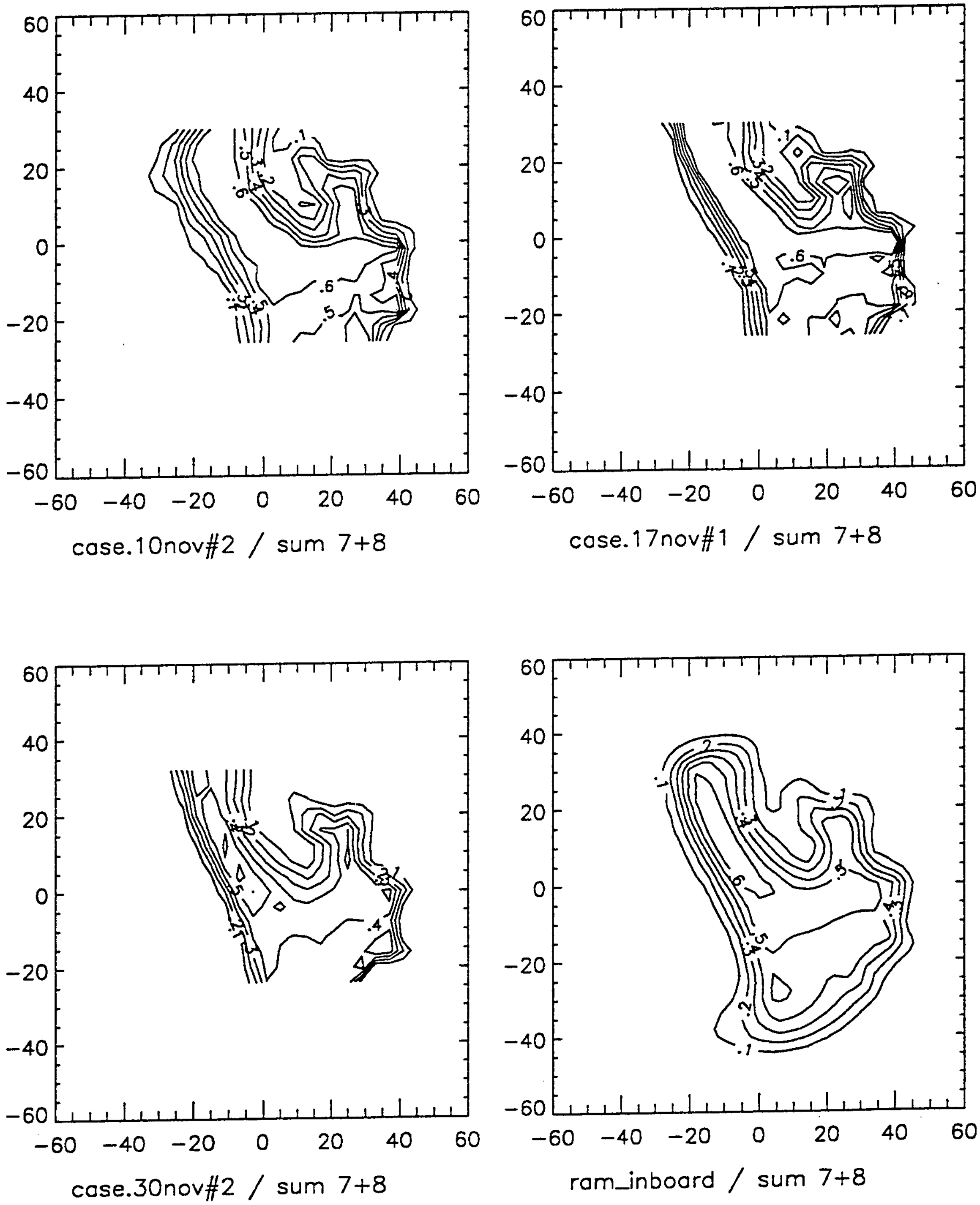

Figure 8. Ram inboard detector data and reconstructed CALSYS data.

3. WAKE RPA SENSOR CALIBRATIONS

The measurement data for the wake end, inboard and outboard detector calibrations consisted of a set of six ASCII files [*Pakula and Cooke*, 1995]. Each of the three detector apertures was measured at two beam energies, 5 and 20 volts. The data files contain CALSYS angles, the current, and the counts/current in thousands for each of the wake channels 9-16.

Since the wake side sensor data was fairly sparse and of mixed quality, each detector was treated as a separate case, as indicated by the analysis tree shown in Figure 2, under the wake_cals directory. No background subtraction was attempted, since the measured data did not extend out far enough to allow a good estimate. The two beam energy cases were kept separate throughout the analysis.

3.1 WAKE END DETECTOR

The wake end detector counts were measured for lines at two twist angle orientations facing the beam, corresponding to azimuth angles of 45 and 315 degrees. An awk script was used to sort with respect to azimuth and scale to counts/current. The output file format was the same as for the ram side lines files:

azimuth polar current f9 f10 f11 f12 f13 f14 f15 f16

No transformation was needed go from the CALSYS to the detector angles because the poles in both frames were aligned.

- the data in channels 9-12 typically ranged from 0.0 to 3.0, with the 20 volt case having the higher values.
- there were only six different measured polar angles at 0, 10, 20, 30, 40, and 47 degrees.

In view of the limited data, it was decided to average the counts at each polar angle, independent of the azimuth angle, which assumes approximate azimuthal symmetry. An awk script was used to read the lines files and calculate averages, and to sum channels 9 to 12 and write an output ASCII file. The ASCII file is similar to the ram side tables, except that there is now only one row representing azimuth angle (arbitrarily set to zero) and just six polar angles. Figure 9 shows the data lines for the wake end detector.

This work was done in subdirectory wake_cals/end.

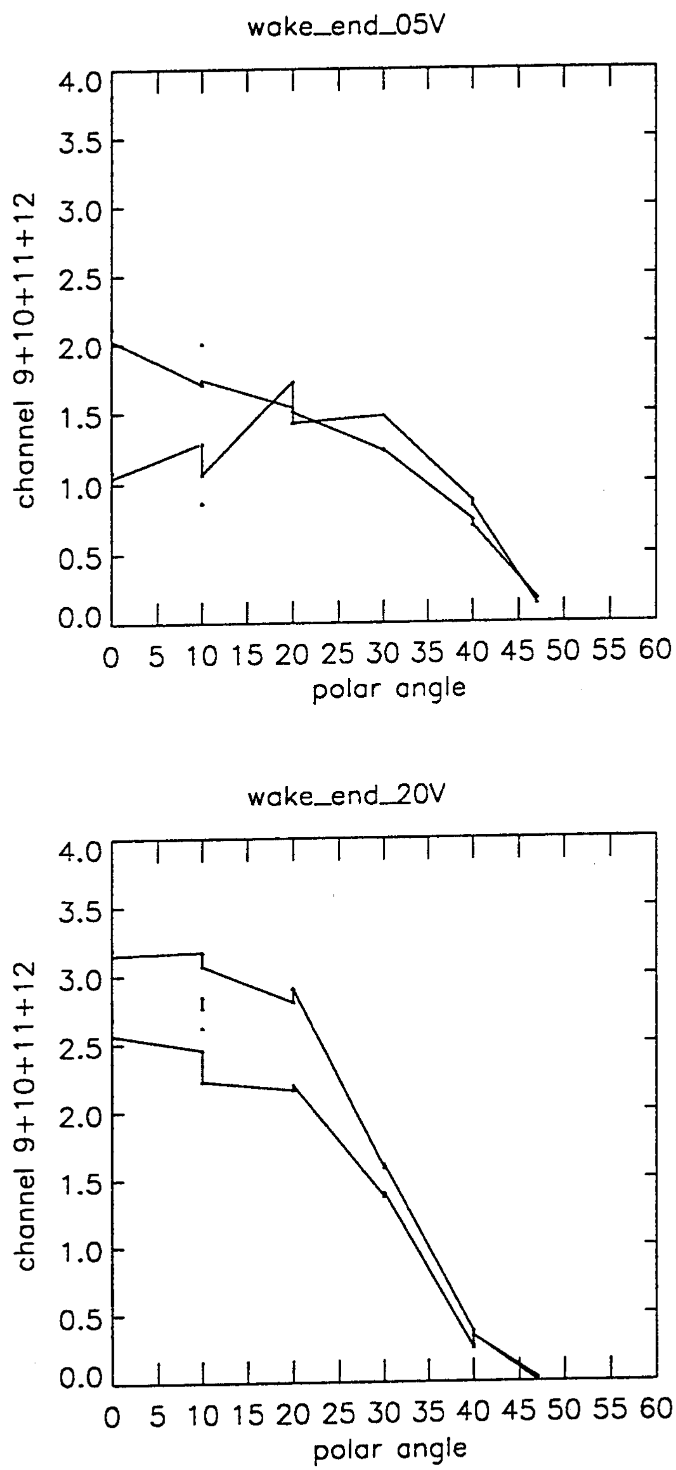

Figure 9. Wake end detector data lines.

3.2 WAKE OUTBOARD DETECTOR

The detector was set facing the beam and was then pre-rotated by angles corresponding to up and down rotations of 12 degrees. The horizontal CALSYS angle was then swept within the range of safe motion. An awk script was used to sort the data with respect to vertical rotation angle and scale to counts/current. An output file was written in an identical format as for the ram side lines files:

angle1 angle2 current f9 f10 f11 f12 f13 f14 f15 f16

where angle1 = vertical CALSYS pre-rotation angle
angle2 = horizontal CALSYS rotation angle

A FORTRAN program, "lines.f", was written to process the lines file. The data on the two horizontal sweeps at +12 and -12 degrees were read in. Any multiple data points were averaged. Since there was no measured data point at the detector origin, a representative point was calculated by taking the average of the six nearest neighbor points (angle2 = -10,0,+10 on the two sweep lines). A transformation from the CALSYS angles to determine the detector polar angle was done, and the detector azimuth angle was ignored. The two data lines were assigned arbitrary azimuths. An awk script was used to sum the data for channels 13 and 14 and write an output ASCII file. Figure 10 shows the data lines for the wake outboard detector. This work was done in subdirectory wake_cals/outboard.

3.3 WAKE INBOARD DETECTOR

The inboard detector calibrations data is similar to the outboard data. The same +12 and -12 degree vertical pre-rotations were done and data was collected for two horizontal CALSYS sweeps. The data was prepared with an awk script and a similar FORTRAN program as for the outboard detector case was used to create the lines files. An awk script was used to sum the data for channels 15 and 16 and write the output ASCII file. This script averaged the data from the two horizontal sweep lines, since they were similar in shape, and assigned an arbitrary azimuth angle. Figure 11 shows the data lines for the wake inboard detector. This work was done in subdirectory wake_cals/inboard.

4. SUMMARY

We have described the processing of the CALSYS calibrations data for the ram and wake side RPA sensors. The method used was to average down the data for each detector aperture along lines emanating from the detector centers. The final output is a set of ASCII files, one for each of the six detector apertures, which characterizes the detector response in counts/current as a function of the polar and azimuth angles, with respect to the aperture normal.

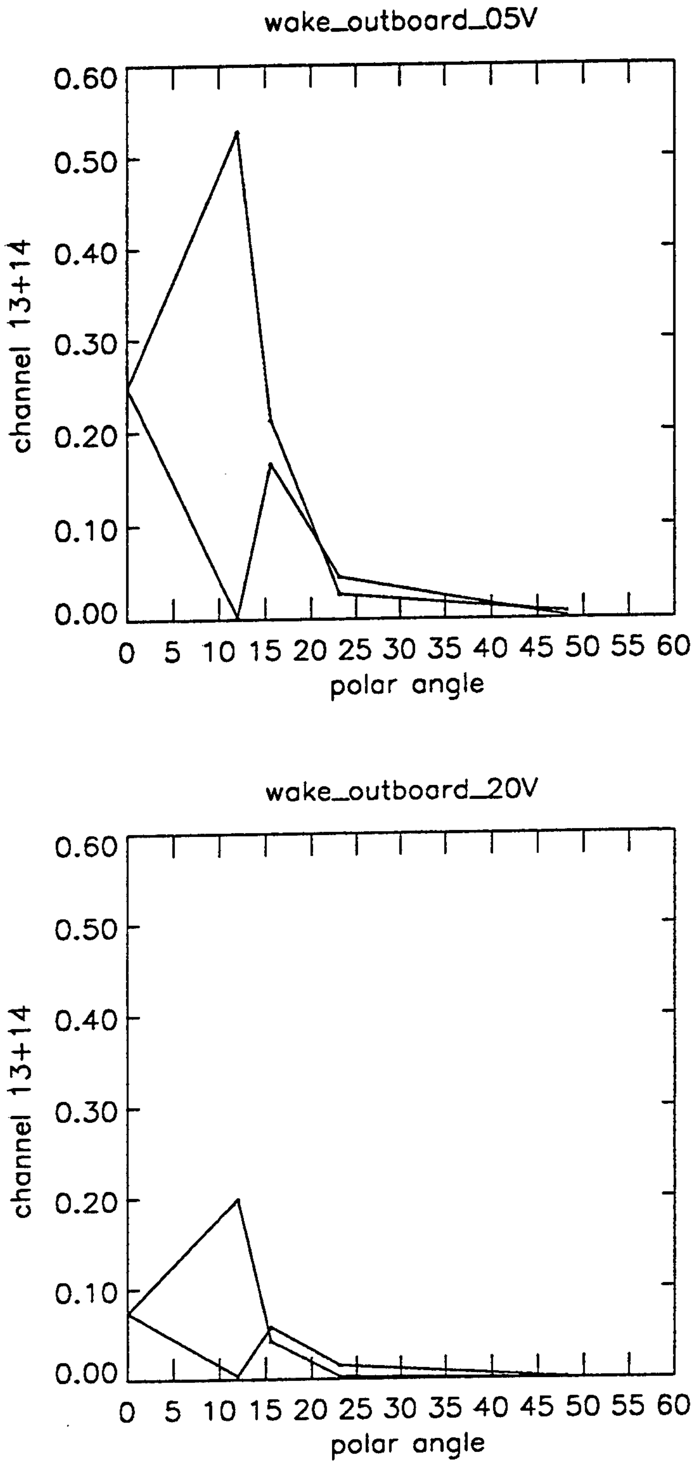

Figure 10. Wake outboard detector data lines.

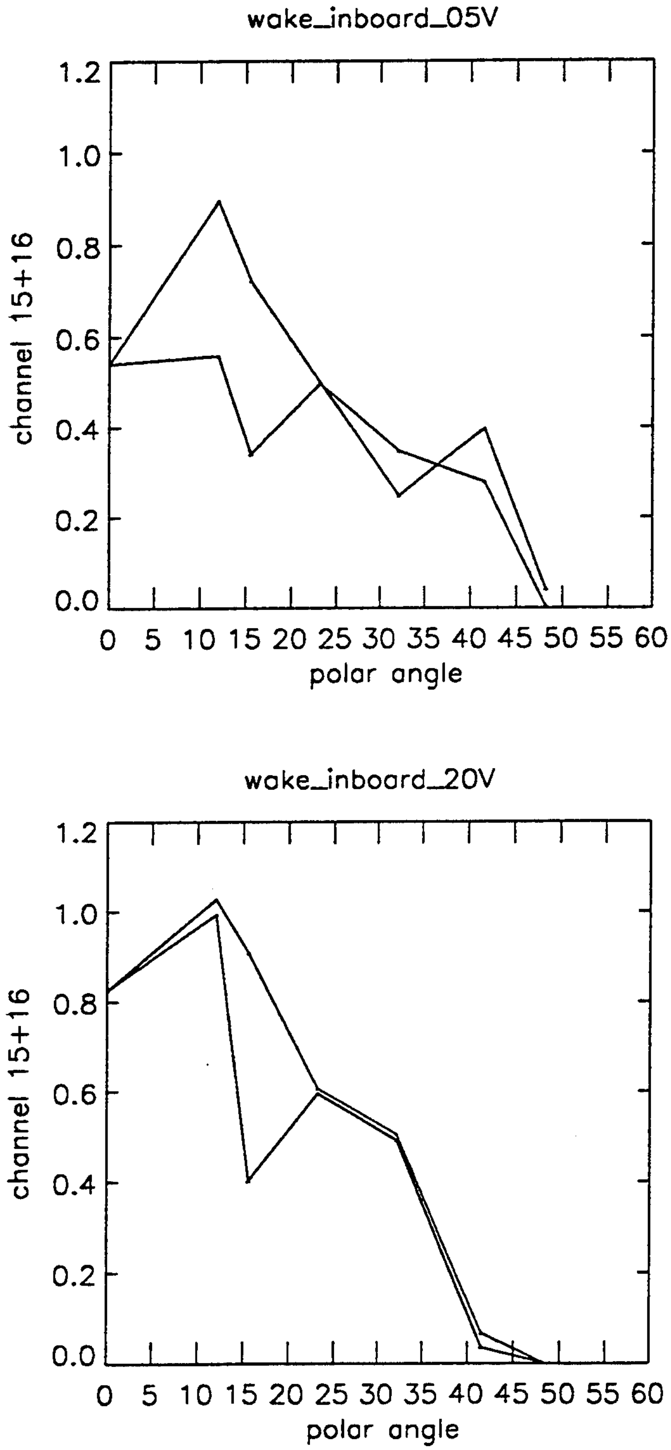

Figure 11. Wake inboard detector data lines.

Figures 6, 7, 8 show the representations of the detector response for ram center, outboard and inboard detectors. Of the ram side cases, the central detector would appear to be the most reliable, since it is based on all eight available measurement cases and doesn't have the added complication of a geometrical offset angle. The ram outboard data is based on just three available measurement cases due to a late MCP replacement. The ram inboard data is based on all eight cases, but has an anomalous distribution.

Figures 9, 10, and 11 show the representations of the wake side detector responses for the end, outboard, and inboard detectors. We have averaged the wake end detector data over all azimuth angles, assuming azimuthal symmetry. The wake inboard and output data was averaged for the two measured horizontal CALSYS sweeps, ignoring azimuth angles. The wake outboard data was averaged in the same manner as the inboard data, but appears to have anomalous behavior.

The above calibrations files were provided as input to the next level of analysis which was used to determine the detector efficiencies as functions of Mach number. These files were subsequently incorporated into the CHAPS and CHUNKS programs, enabling flux and density calculations to be implemented.

REFERENCES

Cooke, D. L., J. Talbot, G. Shaw, "Pre-Flight POLAR Code Predictions for the CHAWS Space Flight Experiment", PL-TR-94-2056, January, 1994, ADA280951.

Enloe, C. L., D. L. Cooke, S. Meassick, C. Chan, and M. F. Tautz, "Ion Collection in a Spacecraft Wake - Laboratory Simulations", J. Geophys Res. No. A8, Vol. 98, Aug. 1993.

Tautz, M. F. "Polar 2 Model of the Wake Shield Experiment", PL-TR-92-2343, December, 1992, ADA266243.

Roth, C. J., *Private Communication*, February 1996.

Pakula, B. and D. L. Cooke, *Private Communication*, June 1995.